

NPS ARCHIVE  
1958  
GMINDER, R.

NEUTRON ACTIVATION ANALYSIS OF  
FISSION - PRODUCT IODINE-131

---

RUSSELL GMINDER  
AND  
JOHN P. TYLER

DUDLEY KNOX LIBRARY  
NAVAL POSTGRADUATE SCHOOL  
MONTEREY CA 93943-5101

2000-01-01  
NAVAL POSTGRADUATE SCHOOL  
MONTEREY, CALIFORNIA









NEUTRON ACTIVATION ANALYSIS

OF

FISSION-PRODUCT IODINE-131

by

Russell Gminder

First Lieutenant , United States Army

and

John P. Tyler

Major , United States Army

Submitted in partial fulfillment of  
the requirements for the degree of

MASTER OF SCIENCE

IN

PHYSICS

United States Naval Postgraduate School  
Monterey, California

1958

NPS ARCHIVE

1958

GMINDER, R.

~~Ther~~  
~~52~~



NEUTRON ACTIVATION ANALYSIS  
OF  
FISSION-PRODUCT IODINE-131

by

Russell Gminder

John P. Tyler

This work is accepted as fulfilling  
the thesis requirements for the degree of

MASTER OF SCIENCE

IN

PHYSICS

from the

United States Naval Postgraduate School



## ABSTRACT

It is sometimes necessary to know the exact isotopic composition of radioactive preparations. Non-radioactive isotopes in small amounts may be present in these preparations. In this investigation, activation analysis techniques were applied to carrier free I-131 to detect and to measure the I-127 present. Although activation analysis has been applied extensively to detecting impurities in inert materials, it has not been employed generally for the detection of isotopes or impurities in radioactive preparations. An I-131 sample was irradiated with thermal neutrons at a flux of  $5 \times 10^6$  neutrons/cm<sup>2</sup>/sec. The gamma spectrum of the irradiated material was determined, and the quantity of I-128 produced was computed. The amount of I-128 found indicated the presence of  $5.7 \times 10^{18}$  atoms of I-127 per millicurie of I-131, or a concentration of inactive iodine  $1.5 \times 10^5$  times that of the radio-iodine.

The writers are indebted to Professor William W. Hawes of the United States Naval Postgraduate School for his professional assistance and his patient encouragement in this investigation.



## TABLE OF CONTENTS

Section	Title	Page
1.	Introduction	1
2.	Neutron Activation	5
3.	Scintillation Spectrometry	8
4.	Analysis	16
5.	Equipment Description	21
6.	Conclusions	26
7.	A Selected Bibliography	28



## LIST OF ILLUSTRATIONS

Figure		Page
1.	Decay Schemes of I-131 and I-128	4
2.	Spectral Shape of I-131	9
3.	Typical Calibration Plot	11
4.	Spectral Shape of I-128	13
5.	Composite Shape from Irradiated I-131	15
6.	Sample Calculation	20
7.	Sample Holder	22
8.	Reactor and Console	23
9.	Spectrometer Room	25





## 1. INTRODUCTION

The technique of employing neutron activation for the detection of trace element impurities in another material began in 1936 with the work of Hevesy and Levi [1] in which a small amount of dysprosium was detected in a sample of yttrium. The utility of this method, including its limits of detection, was summarized in 1953 by Leddicotte and Reynolds [2]. The major advantages of the method as shown by these authors are its extreme sensitivity, its tendency to be specific because the characteristic radiations are known for many radio-isotopes, the requirement of only small samples, the fact that testing is frequently non-destructive in nature, and the accuracy attainable may greatly surpass that of other methods.

Leddicotte and Reynolds report no applications of activation analysis techniques for the detection of non-radioactive trace elements in a radioactive material. If one considers the situation in which the inert trace substance is an isotope of the same element as the bulk of the radioactive material, it is apparent that normal chemical analysis techniques are inapplicable. Activation analysis, however, offers some promise for this problem. In this investigation, the writers, have sought to determine the feasibility of applying activation analysis to the detection of inert isotopic impurities in radioactive preparations.



It may be expected that the relatively intense emissions of the bulk of the material will mask those of the activated impurity. To a large extent this difficulty can be overcome by employing gamma-ray spectrometry. In this way the characteristic spectra may facilitate detection. This will depend on the spectrometer resolution which becomes important when the major gamma emissions of the bulk material and the activated isotope are of nearly the same energy.

I-131 is obtained by chemical separation from fission products, and is thus "contaminated" by any other iodine isotopes which are produced in fission [7,12]. When the separation is accomplished without adding iodine, the preparation is referred to as being carrier-free. Isotopes present after moderate cooling time are inactive I-127 and the long half-life isotope, I-129, in addition to I-131 and I-133. By radiochemical assay, the purity of carrier-free I-131 is reported to be better than 99 percent I-131 and less than 1 percent I-133.

If I-127 is to be detected by activation, it must first have sufficiently large thermal neutron cross section for adequate amounts of I-128 to be formed; and secondly, the major gamma emission energy of I-128 must be sufficiently far from the major emissions of I-131 and I-132 for the spectrometer to resolve it. The cross section of I-127 for thermal neutrons is about 6 barns ( $6 \times 10^{-24} \text{ cm}^2$ ) which, although small, appeared sufficient for activation to be successful with the moderate flux available.



The major gamma ray emissions of I-131, I-132, and I-128 are a 0.364 Mev gamma ray, a 0.670 Mev gamma ray, and a 0.455 Mev gamma ray respectively. That is, these particular gamma rays are produced after each isotope has decayed by a beta process; hence, they represent the decay of excited xenon isotopes. (See Figure 1) Since these energies differ by about 20 percent, and since resolution to within 10 percent or better can be attained, resolution of the I-128 emission as a distinct spectral quantity is assured.

The above considerations led the authors to select carrier-free I-131 as the radioactive preparation to be investigated, and I-127 as the inert impurity to be detected. In brief, the procedure employed consisted of the following steps: First, a sample of I-131 was irradiated in the AGN 201 Reactor. The sample was then inserted in a Tracerlab Stepwise Scanning Spectrometer. The spectrum of the sample thus obtained was analyzed for the presence of the characteristic 0.455 Mev peak due to I-128. The observed peak, when corrected for decay and for the I-131 background, permitted the amount of I-127 originally present to be calculated.



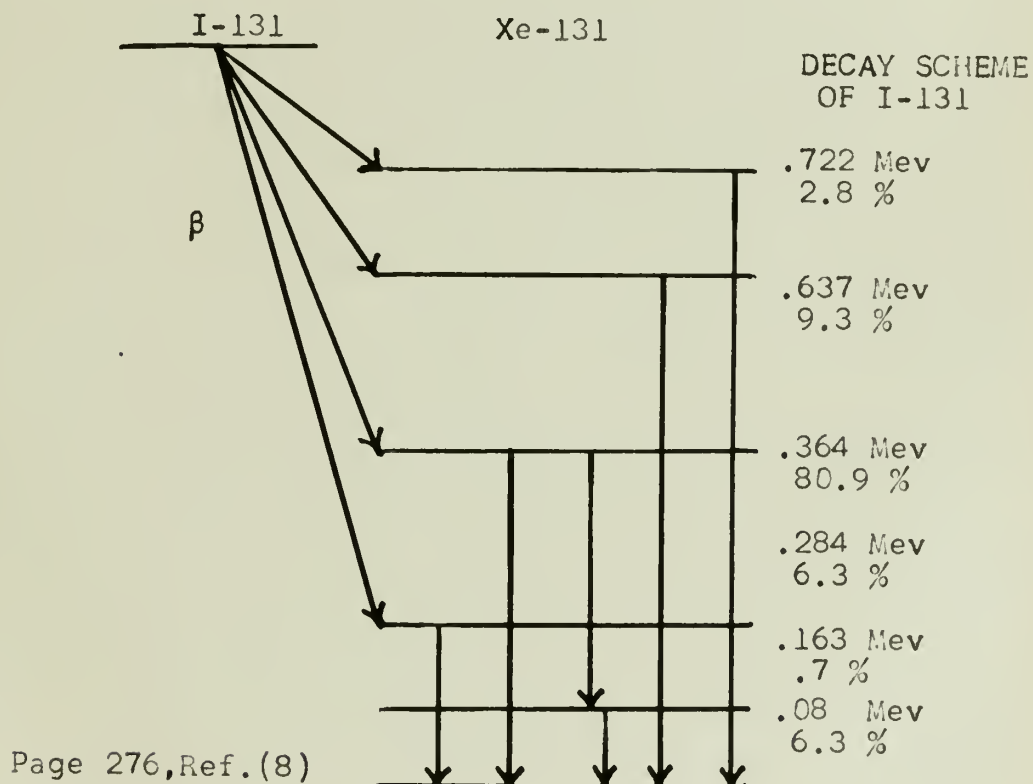
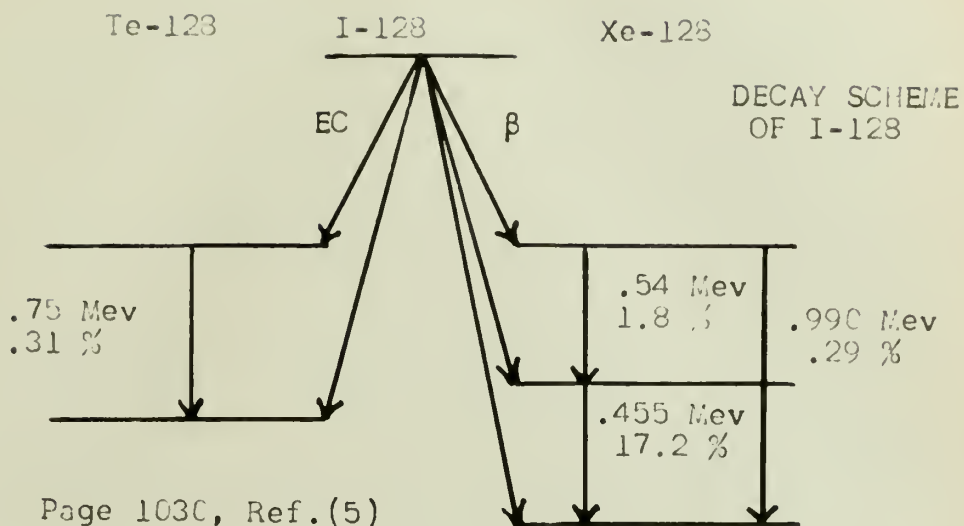


FIGURE 1





## 2. NEUTRON ACTIVATION

The amount of I-128 produced in an irradiation is given by the relationship:

$$N_{128} = \frac{N_{127} \sigma_{127} \phi}{\lambda_{128}} (1 - e^{-\lambda_{128}t}) ,$$

where  $N_{128}$  is the number of I-128 present after an irradiation period,  $t$ , at a flux level  $\phi$ . The terms  $\sigma_{127}$  and  $\lambda_{128}$  are the thermal neutron cross section of I-127 and the decay constant of I-128, respectively. Since  $\lambda_{128} = 2.77 \times 10^{-2} \text{ min}^{-1}$ , it can be seen that five half-lives, or 125 minutes, of irradiation will make the value of this term 97 percent of its asymptotic maximum. If the half-life were very long, impractically long irradiations would be required. Very short half-life isotopes on the other hand decay too rapidly for effective detection. Leddicotte and Reynolds recommended isotopes with half-lives ranging from 10 minutes to several days, as being suited for activation analysis. I-128 with a half-life of 25 minutes is within this range.

The I-131 preparation was obtained from Oak Ridge National Laboratory, Radio-isotopes Sales Department. The first sample of I-131 consisted of 0.3ml in a glass bottle, and was assayed at 34.94mc/ml. It was diluted to a volume of 10ml, (1mc/ml). From this solution 1.8ml were transferred to the sample holder for irradiation. The sample holder is illustrated in Figure 7 and described in Section 5.



Each sample was inserted in the reactor via the "glory hole" and positioned at the center of the core, where the thermal neutron flux is a maximum. All sample irradiations were conducted at a power level of 100 milliwatts. The central thermal neutron flux corresponding to this power level is rated as  $4.5 \times 10^6$  neutrons/cm<sup>2</sup>/sec. Following the 125 minute irradiation, the sample was removed from the reactor and transferred to the scintillation spectrometer for analysis.

The spectroscopic examination of the first sample after irradiation resulted in a conclusion that the I-131 background was masking the I-128. Another sample was prepared by concentrating the contents of six vials, each of which contained approximately 100 microcuries of I-131 that had been decaying for about two years. It was felt that, by lowering the background due to I-131, the presence or absence of I-127 could be more clearly established. The sample was irradiated and the presence of I-127 was clearly substantiated. Thus, it became necessary to establish a threshold of detection. This was done by the activation of samples whose I-131 activity was made progressively less either by dilution or by decay.

Other irradiations were performed to generate data necessary for the quantitative analysis. An empty sample holder was irradiated and analyzed; no appreciable activity was observed. A solution containing a known amount of I-127 was irradiated in order to generate the I-128 spectral shape. This



sample was also used to obtain a calibration between the observed I-128 activity in the I-131 samples and the amount of I-127 present.



### 3. SCINTILLATION SPECTROMETRY.

A recent report on scintillation spectrometry by R.L. Heath [3] proved to be most applicable for this investigation. In this, a catalogue of gamma ray spectra, the concept of spectral shapes is clearly explained, and the reader is referred to this article for details. A given radioactive nuclide when examined with a spectrometer, will yield an intensity distribution as a function of energy for the emitted gammas, their Compton smears, and backscattered rays. If the backscattering contribution is reduced greatly by the shielding arrangement, or eliminated mathematically, then the intensity distribution curve as a function of energy is called the characteristic "spectral shape" of the nuclide. (See Figure 2). If more than one nuclide is present in a sample, the obtained envelope is a composite of the appropriately weighted individual spectral shapes.

Intensity-versus-energy measurements were made for several types of samples. The sample types were: background, an irradiated empty sample holder, a sample of irradiated I-127, a sample of non-irradiated I-131, and samples of irradiated I-131 with various specific activities and decay times.

A number of spectrometer gain, voltage, discriminator, and bias settings were examined. The most linear and most stable response with suitable resolution was obtained when these settings were such as to give a range of 700 Kev for the 50 channels, or a 14 Kev increment per channel. A Sola





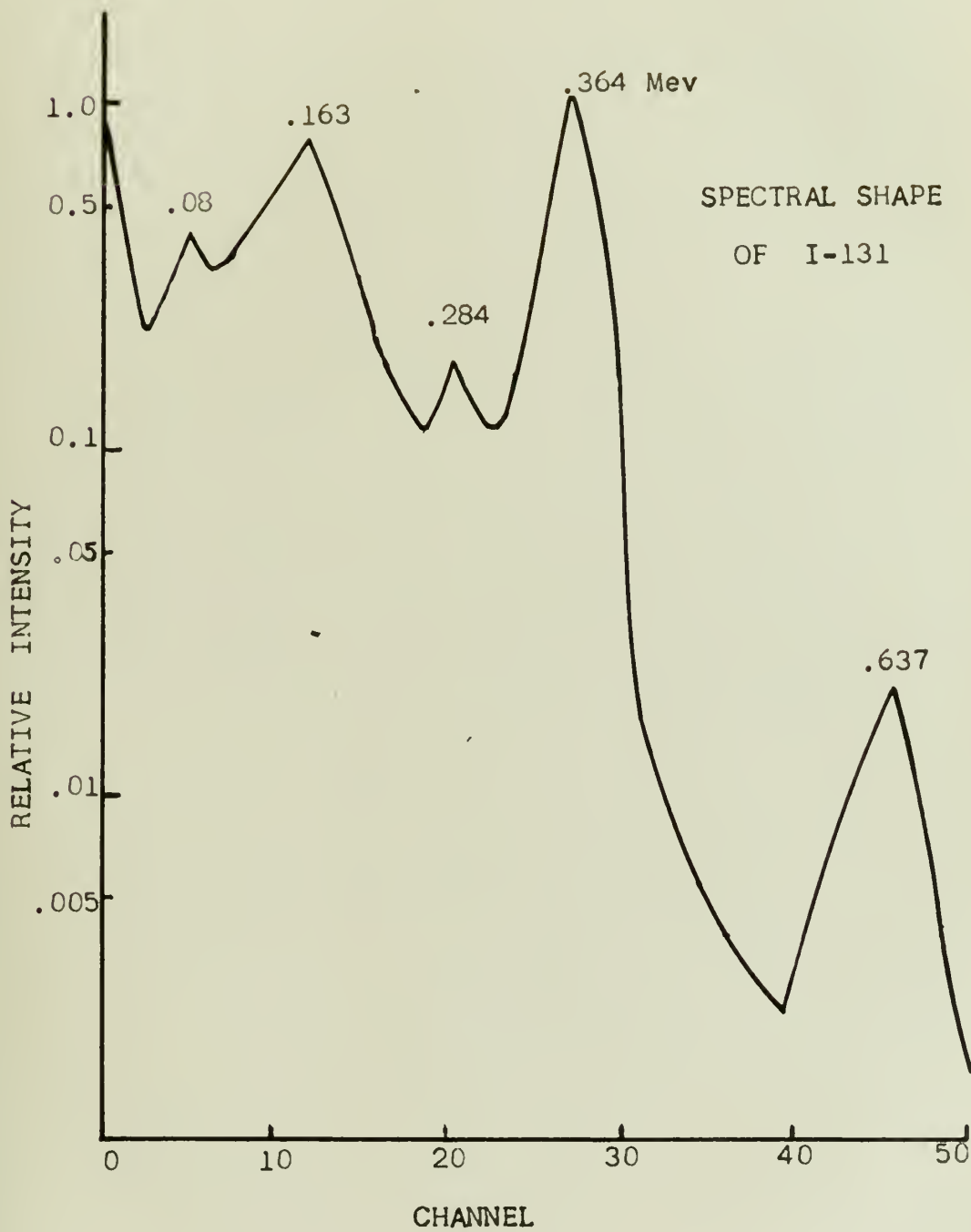


FIGURE 2



transformer was interposed between the spectrometer and the line to insure good voltage stability. All chassis components were kept on continuously to insure maximum thermal stability.

The resolution time of the spectrometer is such that coincidence losses become significant for total count rate in excess of 4000 counts per second. During the examination of the higher specific activity, irradiated, I-131 samples, this limiting value was closely approached.

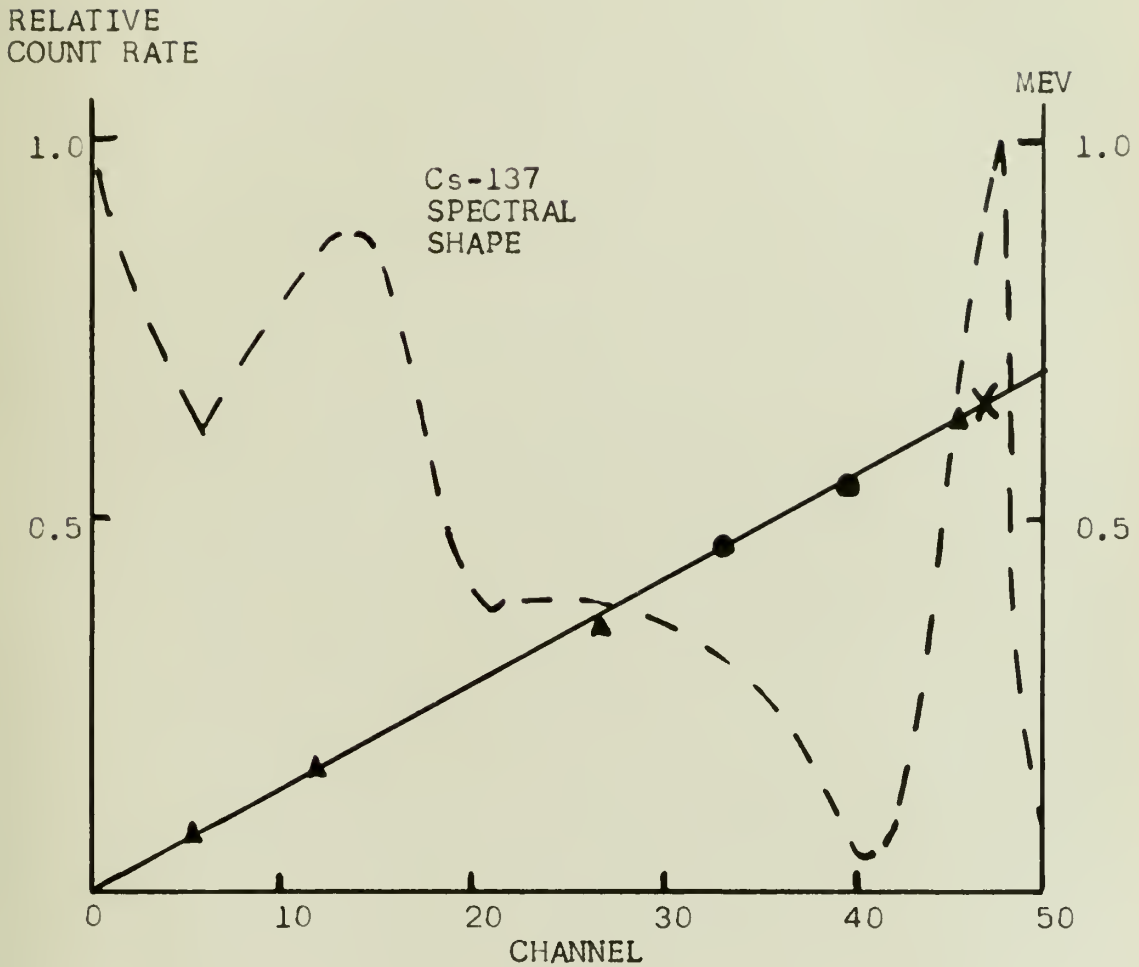
The response of the amplifier is rated as linear within 1 per cent. Many calibrations at various spectrometer settings were performed using Pa-234, Zn-65, Co-60, Cs-137, and I-131 as calibrating sources. Except for excessively high total count rates, as mentioned above, the linearity was observed to be within the specification. For the final experimental runs, Cs-137 and I-131 were used exclusively as the calibration sources. (See Figure 3)

A 50 minute per channel background examination plus numerous other shorter background checks showed that the average background count rate in each of the first 10 channels was about 20 counts per minute. This value gradually diminished to essentially zero in the higher channels. Since during the major sample runs the channel count rates were in the thousands, background effects were not included.

The irradiated empty sample holder, when counted, showed a slight amount of activity, about 2 to 4 counts per minute above background. No photopeaks were observed. Hence, the



TYPICAL  
CALIBRATION  
PLOT



- ▲ -- I-131 Photopeaks, ( Non-irradiated )
- -- I-128 Photopeaks, ( Irradiated I-127 )
- X -- Cs-137 Photopeak,

FIGURE 3



contribution of the sample holder may be ignored. The samples of irradiated I-127 and non-irradiated I-131, when examined and corrected for decay, gave the spectral shapes shown for I-128 and I-131 respectively. (See Figures 2 and 4) These shapes were used in the analysis of the irradiated I-131 samples for the presence of I-128. Using the spectral shape subtraction approach as described by Heath, the effective peak-to-total ratio for the 0.455 Mev emission of I-128 was obtained. This peak-to-total ratio for the experimental configuration employed was 0.185. The subtraction scheme was applied to the irradiated I-131 samples to eliminate the I-131 contribution to the composite spectral shape.

The peak-to-total ratio is the ratio of the area under the photopeak to the area under the entire spectral shape, provided one has a monoenergetic source. In the event there are two or more emission energies in the source, one must use a subtraction scheme. This approach involves fitting an idealized monoenergetic spectral shape, photopeak to photopeak, on the highest energy photopeak in the sample spectrum. Once fitted, this spectral shape is subtracted from that of the sample, leaving the contribution of lesser energy peaks only. Successive applications of this approach permit the composite spectral shape to be resolved into its components. The peak-to-total ratio for each component may then be determined.

To determine the peak-to-total ratio for a monoenergetic emission or for a resolved component, one fits a Gaussian





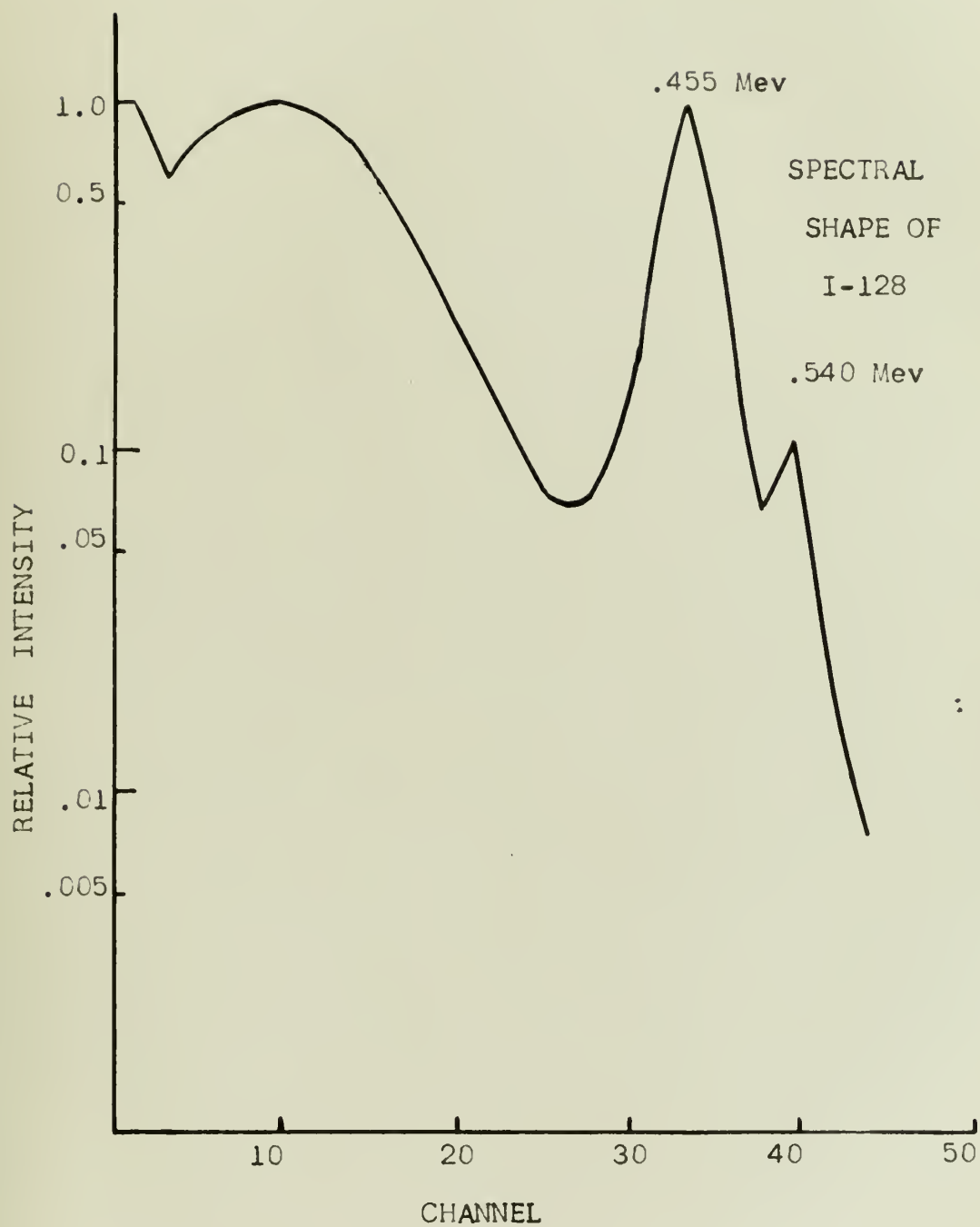


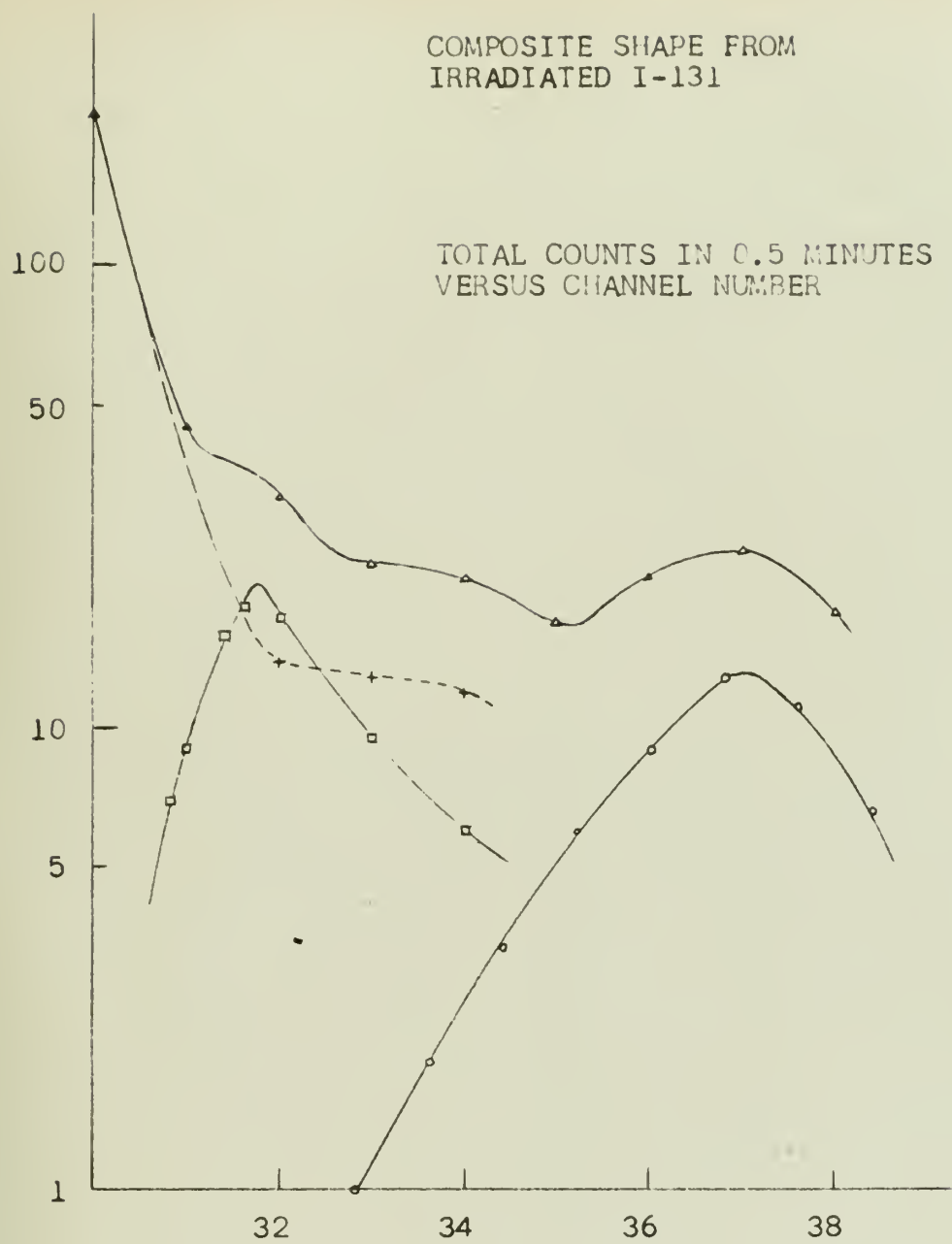
FIGURE 4



distribution to the high energy side of the photopeak. It is assumed that the area under the Gaussian distribution is the same as that area under the experimental photopeak. The area under the balance of the spectral shape may be determined by any appropriate method. The relationship of area to maximum ordinate enables one to measure, in effect, the area under the photopeak by measuring its height. If the peak-to-total ratio has previously been determined, then one can immediately calculate the number of events of the particular energy that occurred in the scintillation crystal.

The emissions of I-128 of energies higher than 0.455 Mev contribute only 11 percent of the total gamma emission. Therefore, by using the spectral shape subtraction technique to adjust the I-128 shape to that of its equivalent monoenergetic 0.455 Mev spectral shape, little accuracy is lost. Small percentage errors in fitting these higher energy peaks prior to subtraction are reduced nearly ten-fold in their effect on the equivalent 0.455 Mev spectral shape. In view of these considerations it is felt that the value of 0.185 for the peak-to-total ratio is accurate to within 1 percent. An example of the irradiated I-131 preparation with composite spectral shapes of I-131 and I-128 is shown in Figure 5.





- △ IRRADIATED I-131
- + NON-IRRADIATED I-131
- I-132 PHOTOPEAK ( 0.525 Mev )
- I-128 PHOTOPEAK

FIGURE 5



#### 4. ANALYSIS.

In the last section the concept of peak-to-total ratio was discussed. The area under the photopeak was assumed to be that under a Gaussian distribution fitted to the high energy side of the photopeak and having the same value for its maximum ordinate. Thus, the area under the photopeak is 2.56 times the value of the maximum ordinate. In terms of the emission rate under the photopeak  $R_p$ , and the total emission rate  $R_t$ , the peak-to-total ratio  $p$  is :

$$p = \frac{R_p}{R_t} .$$

If there were no absorption losses, and if the detection efficiency were 100 percent, the absolute emission rate  $R$  would be equal to the total emission rate  $R_t$ . The methods employed to obtain these corrections will be discussed in later paragraphs. The resultant equation for the determination of the absolute emission rate  $R$  is :

$$R = \frac{R_t}{A e_t} = \frac{R_p}{\left[ \frac{R_p}{R_t} \right] A e_t} = \frac{R_p}{p e_t A}$$

where  $A$  is the absorption correction, and  $e_t$  is the detection efficiency. For given emission,  $p$ ,  $A$ , and  $e_t$  can be determined independently and are independent of the intensity of the emission within the normal range of operation. Hence the absolute emission rate for any sample can be calculated as





soon as the maximum ordinate of the photopeak has been determined.

The absorption correction was computed by using the gamma-ray absorption coefficient of water for the sample solution, and an average of water and carbon gamma-ray absorption coefficients for the plastic of the sample holder. The value obtained was  $A = 0.935$ .

The total absolute detection efficiency  $e_t$  was interpolated from disk source efficiency calculations given by R.L. Heath. [9]. The sample holder volume was partitioned into thin layers, or disks. The disk source efficiency for each layer was then determined. The mean of the efficiencies thus determined was  $e_t = 0.0256$ .

The 0.455 Mev emission of I-128 accounts for 17.2 percent of the total decay. [5]. The decay constant  $\lambda_{128}$  of I-128 is  $2.77 \times 10^{-2} \text{ min}^{-1}$ . The absolute emission rate  $R$  for 0.455 Mev emission is related to the number of I-128 atoms present,  $N_{128}$ , in the following manner :

$$\frac{R}{0.172 \lambda_{128}} = N_{128} = 209.9 R$$

The number of I-128 atoms was always obtained from a decay corrected value of  $R$  corresponding to the time of termination of irradiation.  $N_{128}$  is related to the original number of I-127 atoms present,  $N_{127}$ , by the relationship, as shown on page 5.



The examination of the irradiated I-131 for the presence of I-128 was accomplished by taking measurements only in the channels in the immediate vicinity of the 0.455 Mev photopeak, and recycling over these same channels as rapidly as possible during the decay. All such measured count rates were decay corrected to the time of the end of irradiation. After this correction all count rates for each respective-channel were averaged. These averaged values were then plotted and the spectral shape subtraction technique applied to obtain the I-128 contribution to the composite spectrum.

For the I-131 sample taken from the two year old preparation, no accurate value of the amount of I-131 originally present was known. Therefore, any calculation of the amount of I-127 in this sample is not relatable to the amount of I-127 per millicurie of I-131.

Another sample of I-131 had been decaying for 36 days. It consisted of  $5 \times 10^{-3}$  ml of stock solution diluted to fill the sample holder. The stock solution was assayed at Oak Ridge as being 29 mc/ml of I-131. Hence at the time of examination the specific activity of the stock solution was 1.35 mc/ml. The spectral shape obtained indicated the presence of I-128, but was not sufficiently well defined for reliable evaluation of I-127 content. This, then, constitutes the detection limiting activity.

A third sample was prepared from an I-131 solution that had decayed for 81 days. A local assay of this solution agreed precisely with the Oak Ridge assay of 35 mc/ml for 0.3 ml.



The 0.3 ml was diluted to 10 ml, of which 6 ml were taken, concentrated, and put into a sample holder. This sample was irradiated, and then examined as described above. The decay corrected photopeak was  $42 \pm 2$  cpm/unit energy interval, so that  $R_p = 108 \pm 5$  cpm. This represents  $8.6 \times 10^{19}$  atoms of I-127 in the sample, or  $18.1 \pm 0.9$  mg. A sample of 14 mg of I-127 was irradiated under the same circumstances as the I-131 sample. The decay corrected photopeak height was 81.5 cpm/unit energy interval. Using this direct calibration the amount of I-127 in the I-131 sample was 7.49 mg as compared to the calculated value of 18.1 mg. The calculated value is 2.4 times the direct comparison value. It is probable that the discrepancy is due to error in the assumed value of the flux. See Figure 6 for a sample calculation.



# SAMPLE CALCULATION

VALUES OF CONSTANTS:

$$\begin{aligned}
 p &= 0.185 & e_t &= 0.0256 & A &= 0.935 \\
 \phi &= 4.5 \times 10^6 \text{ n/cm}^2/\text{sec} & \lambda_{128} &= 2.77 \times 10^{-2} \text{ min}^{-1} \\
 \sigma_{127} &= 6.3 \times 10^{-24} \text{ cm}^2 & &= 4.62 \times 10^{-4} \text{ sec}^{-1}
 \end{aligned}$$

OBSERVED HEIGHT OF I-128 PHOTOPEAK :

42 cpm/unit energy interval.

AREA UNDER I-128 PHOTOPEAK :

$$R_p = 2.56 \times 42 = 108 \text{ cpm}$$

ABSOLUTE EMISSION RATE FOR 0.455 MEV GAMMA OF I-128 :

$$R = \frac{R_p}{p e_t A} = 2.42 \times 10^4 \text{ cpm}$$

NUMBER OF I-128 ATOMS AT END OF IRRADIATION :

$$N_{128} = \frac{R}{0.172 \lambda_{128}} = 209.9 R = 5.09 \times 10^6 \text{ atoms}$$

NUMBER OF I-127 ATOMS IN SAMPLE :

$$\begin{aligned}
 N_{127} &= \frac{\lambda_{128} N_{128}}{\sigma_{127} \phi} \times \frac{1}{(1 - e^{-\lambda_{128} t})} = \\
 &8.55 \times 10^{19} \text{ atoms}
 \end{aligned}$$

NUMBER OF MG OF I-127 IN SAMPLE :

$$\frac{N_{127} \times A_{127}}{6.02 \times 10^{23}} = \frac{8.55 \times 10^{19} \times 127 \times 10^3}{6.02 \times 10^{23}} = 18.1 \text{ mg}$$

FIGURE 6





## 5. EQUIPMENT DESCRIPTION.

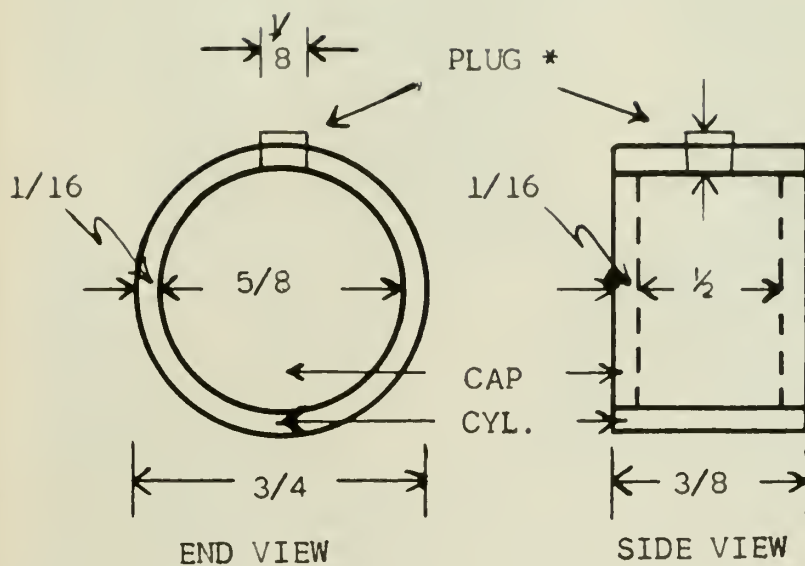
The Aerojet-General Nucleonics Model 201 Research Reactor has been described [6]. The reactor, when operating at a rated power level of 100 milliwatts, has a central core thermal neutron flux  $4.5 \times 10^6$  neutrons/cm<sup>2</sup>/sec, a flux level comparable to that attainable with moderate intensity Ra-Be or Po-Be sources.

The "glory hole" of the AGN 201 reactor is an aluminum tube, approximately one inch in diameter, which passes horizontally through the center of the reactor. Two plug rods are normally inserted in the "glory hole". These rods are so constructed that the materials of their inner ends match the reactor core, reflector, and gamma ray shield for that volume not occupied by samples being irradiated. The general arrangement of the reactor and its control console are shown in Figure 8.

The sample holders employed were designed to pass freely through the "glory hole". Each holder was assembled and fused with glacial acetic acid. The dimensions and design of the sample holders are shown in Figure 7. As a further safeguard against leakage the sample holder was sprayed with an acrylon plastic sealer.

A Tracerlab Stepwise Scanning Spectrometer, RLP-6 III, was employed in this investigation. Its major components are: a NaI (Tl) scintillation detector, a power supply, a high voltage supply, a pulse amplifier and shaper, a threshold discriminator, a stepwise-scanning single window





\* PLUG SLIGHTLY TAPERED

ALL DIMENSIONS IN INCHES

MATERIALS:

PLUG, END CAPS -- LUCITE

CYLINDER -- POLYSTYRENE

SAMPLE HOLDER

FIGURE 7





This photograph shows the AGN 201 Reactor and its control console. Lt. Gminder is inserting the plug rod into the "glory hole". Major Tyler is at the control console. Professor Hawes is supervising the operation.

#### REACTOR AND CONSOLE

FIGURE 8



discriminator, and an automatic read-out scaler and printer. The detector head consists of a  $1\frac{1}{2}$ "x1" NaI(Tl) scintillation crystal coupled to Dumont Type 6292 photomultiplier tube, both components being housed in a light-proof metal casing. This housing is coupled to a sample stage, and the whole assembly is encased by a three inch thick cylindrical lead shield. The high voltage supply provides a well regulated voltage from 500 to 5000 volts in 10 volt increments. Its stability is rated as less than 0.02 percent drift per day, and its regulation is such that a 1 percent change in line voltage will cause no more than 0.2 volts change in the output high voltage. The pulse amplifier is linear to within 1 percent and has a rise time of 0.25  $\mu$ sec. The stepwise scanning element moves a fixed window, 5 volts in width, through 50 steps, or channels, covering a range of 0 to 255 volts. The automatic read-out scaler and printer work in conjunction with the scanning element so that as information obtained for a given channel is recorded, the scanning element advances to the next higher channel. Upon completion of each recording cycle, counting in the next higher channel commences. The read-out information consists of the channel number, the number of counts occurring in this channel during a selected interval of time, and the time interval in minutes. The spectrometer arrangement is shown in Figure 9.







This photograph shows the spectrometer arrangement. From left to right, the spectrometer system consists of the read-out typewriter, the RLP-6 cabinet, and the lead shield with the detector unit inside.

SPECTROMETER ROOM

FIGURE 9



## 6. CONCLUSIONS.

This investigation has shown that an inert isotope, I-127, is present in carrier-free I-131. For the specific sample that was quantitatively measured this I-127 content was found to be 1.2 mg of I-127 per mc of I-131. This investigation has demonstrated that studies of this nature can be successfully pursued with low intensity neutron sources provided that gamma ray spectrometry is employed for radiation analysis. This conclusion is supported by recent studies at the U.S. Naval Hospital at Bethesda, Maryland. [10]. Workers there have sought to determine the carrier-free status of radioisotopes by neutron activation. Their investigation was specifically applied to the detection of Cu-63 in Cu-64, detection being indicated by the increase in activity. Such increases were reported, indicating that Cu-63 is present in carrier-free Cu-64. The techniques utilized here, however, should greatly improve the sensitivity of that determination. Since the sensitivity of this analysis is directly proportional to the neutron flux level, one may conclude that, by increasing the flux level from  $10^6$  to  $10^{12}$  neutrons/cm<sup>2</sup>/sec, a sensitivity of 0.018  $\mu$ g may be achieved. This is comparable to the 0.002  $\mu$ g sensitivity quoted by Leddicotte and Reynolds, with inactive materials for I-128, using a flux of this magnitude. [2,12].

The successful application of neutron activation analysis to a radioactive preparation is dependent mainly on two factors. First of all, the combination of the thermal



neutron cross section of the nuclide sought and the available neutron flux level must be such as to assure that a detectable activity will be produced. Secondly, the emission of the radioactive preparation, its decay products, and the activated products other than that sought must not be sufficiently close, energy-wise, to that of the sought activated nuclide so as to mask its presence. This second factor is cited by Wahl and Bonner as being one of the two major limitations of activation analysis. [11].



## 7. A SELECTED BIBLIOGRAPHY.

1. G. Hevesy and H. Levi, Kgl. Danske Videnskab Selskab Math-fys. Medd., 14, No.5, 1936.
2. G.W. Leddicotte and S.A. Reynolds, Neutron Activation Analysis, AECD-3489, United States Atomic Energy Commission, Oak Ridge National Laboratory, January, 1953.
3. R.L. Heath, Scintillation Spectrometry Gamma-Ray Spectrum Catalogue, AEC Research and Development Report IDO-16408, United States Atomic Energy Commission, Idaho Operations Office, July, 1957.
4. R.L. Heath and F. Schroeder, The Quantitative Techniques of Scintillation Spectrometry as Applied to the Calibration of Standard Sources, AEC Research and Development Report IDO-16149, United States Atomic Energy Commission, Idaho Operations Office, April, 1955.
5. N. Benczer et al, Investigations of I-128, The Physical Review, Vol. 101, No.3, pp 1027 to 1030, 1956.
6. A.T. Biehl et al, Compact, Low-Cost Reactor, Nucleonics, Vol. 14, No.9, pp 100 to 103, McGraw-Hill Publishing Co., September, 1956.
7. A.F. Rupp et al, Production of Fission-Product Iodine 131, ORNL-1047, United States Atomic Energy Commission, Oak Ridge National Laboratory, December, 1951.
8. S. Kinsman et al, Radiological Health Handbook, U.S. Dept. of Health, Education and Welfare, Public Health Service, P B 121784, Cincinnati, Ohio, 1957.
9. S.H. Vegors, Jr., L.L. Marsden, and R.L. Heath, AEC REPORT IDO-16370, (unpublished); a portion of which pertaining to the absolute detection efficiency for disk sources and 1½"x1" NaI(Tl) scintillation crystals was obtained by private communication with R.L. Heath, Atomic Energy Division, Phillips Petroleum Co., May, 1958.
10. R.P. Spencer et al, Carrier content by Neutron Activation Applied Radiation Section, Nucleonics, Vol. 15, No.12, page 93, McGraw-Hill Publishing Co. December, 1957.
11. A.C. Wahl and N.A. Bonner, Radioactivity Applied to Chemistry, Par. 5.2, pp 88 to 90, John Wiley and Sons, Inc., 1951.
12. F.R. Bruce et al, Process Chemistry, Series III, pp 360 to 362, McGraw-Hill Book Co., 1956.















thesG52

Neutron activation analysis of fission-p



3 2768 002 02957 1

DUDLEY KNOX LIBRARY